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Simulation of Bi-static Radar System Based on Reflected GPS L5 Signals

Salma Sakhawat[a,b], Muhammad Usman[b,c,e], Basharat Mahmood[b,c,d,e,*]

[a]*National Electronic Complex of Pakistan, Islamabad, 44000, Pakistan*
[b]*National University of Science and Technology, Islamabad, 44000, Pakistan*
[c]*Air Weapon Complex, Wah, 47040, Pakistan,*
[d]*National Institute of Electronics, Islamabad, 44000, Pakistan*
[e]*University of Wah, Wah, 47040, Pakistan*

Abstract

Reflected GPS signals can have novel application for remote-sensing as they can provide valuable information about the reflecting surface. This paper focuses on the image formation of stationary targets using GPS L5 reflected signals which are processed based on SAR signal processing techniques. At first the power budget analysis for both reflected GPS L1 and L5 signal is carried out for different target to receiver ranges and results are discussed. The complete imaging scenario has been simulated and images using both reflected GPS L1 and L5 signals are presented. Simulations are carried out for different observation time periods and SNR(signal to noise ratio) is calculated for both L1 and L5 frequency signals and results are compared. The results conclude that the SNR and image resolution for L5 signal is superior as compared to L1 signal. The spatial resolution of image reconstructed for reflected L5 signal based on SAR technique is also improved as compared to GPS L1 signal.

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1. Introduction

The GPS is a worldwide radio navigation system consist of twenty four satellites orbiting round the earth in 6 orbital planes. Direct GPS signals have wide applications for navigation and positioning. Reflected GPS signals or multipath signals contain valuable information regarding the reflecting surface and can be used for remote sensing. However, these reflected signals have very low SNR(signal to noise ratio) at the receiver end. Interestingly, suitable signal processing techniques can be applied which improve the processing gain and thus signals can obtain enough SNR making then suitable for various remote sensing applications.

* Corresponding author.
E-mail address: dgnie@nie.gov.pk

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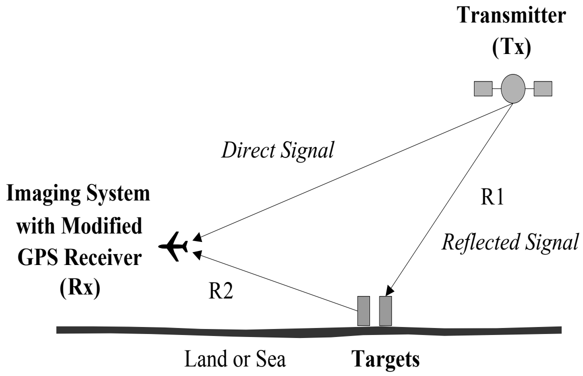

Fig. 1: Schematic representation of imaging scenario

Apart from position and velocity calculation the reflected GPS signals are also used for measuring the ionospheric delay over the ocean[1], soil moisture contents[2] wind speed measurement[3]. The GPS signals reflected from ocean surface contain information about roughness of sea surface which is based on wind speed. Moreover, models are established for the sea state and wind speed extraction from the ocean reflected GPS signals and experiments are also carried out on GPS reflected signals[4]. A. Komjathy,J.AMaslanik,V.U Zavorotny, P.Axelrad and S.J Katzberg presented a research work for the utilization of reflected signal to find the presence of ice, and state of ice on both sea water and fresh water[5]. The idea has extensive applications due to the environmental conditions of inaccessible areas.

This research work describes a bi-static radar imaging system, which uses reflected GPS L5 frequency signals. A GPS satellite, targets and receiving hardware form a passive bi-static SAR(synthetic aperture radar) where the satellite and receiver motion with constant velocity function as a base for synthetic aperture. The scenario is shown in Fig 1. The received signal strength depends on the energy reflected from target inside antenna foot print. In order to improve the resolution of imaging system a large antenna aperture is required which is not feasible for installation in a space craft and is the main limitation in case of real aperture radar. This limitation is overcome by using a SAR where synthetic antenna aperture is generated by using signal processing means rather than physical long antenna. Thus making a narrow beam width which results in improved signal strength and imaging resolution.

A two dimensional image in range and cross range direction based on SAR technique is reconstructed. The range resolution can be improved by increasing the bandwidth B of the transmitted signal and cross range resolution is improved by making synthetic aperture radar giving the narrow the beam width. The spatial resolution in range direction is not only dependent on the wavelength but is also a function of reciprocal of bandwidth with speed of light. The spatial resolution is given by:

$$RangeResolution = \frac{c}{2Bcos\frac{\beta}{2}}, \tag{1}$$

where B is the bandwidth of the transmitted signal and C is the speed of light, is the Bi-static angle between transmitter and receiver. As the transmitted signal bandwidth increases the range resolution improves, where at =0 the system has maximum range resolution as it becomes a mono static SAR. The L5 GPS signal offers enhanced bandwidth as compared to L1 signal thus GPS based SAR can have improved range resolution.

There are several advantages of this kind of system since in case of GPS based passive Bi static radar the need for dedicated transmitter is eliminated as GPS source of illumination is available all over the earth and system will have low power consumption. No frequency allocation is required as GPS satellite transmits signal on its predefined frequency and according to results obtained during this research the system will have enough resolution for remote sensing application which in turn reduce the cost of radar system.

Currently GPS signals are transmitted at L1 (1575.42MHz) frequency with C/A (coarse acquisition) code used as ranging signal which is unique for each satellite. The new GPS L5 (1176.45 MHz) signal has recently been included in GPS signal structure as part of modernization efforts. The first GPS satellite with L5 test payload was launched on March 24, 2009 and few days later test transmission was turned on by GPS control segment[6]. In case of GPS L1 signal the bandwidth is 2.04MHz and C/A code is BPSK modulated with a chip rate of 1.023 MHz i.e. it is repeated every millisecond. GPS L1 signal has low bandwidth and inferior GPS signal power, signal power is further reduced after reflection from target or earth surface, which makes detection almost impossible by conventional signal acquisition approaches[7].

The new L5 signal designed for civilian purposes is transmitted at frequency of 1176.45MHz with chip rate of 10.23 MHz, and 24MHz bandwidth (null to null bandwidth is 20MHz). The L5 signal is Quadrature (Bi-phase shift keying) modulated where in phase component contains a 10230 chip long PRN code and 10 bit Neumann Hoffman code at 1000 chips per second with FEC rate of . Quadrature phase component is also modulated with a different PRN code of 10230 chip long and 20 bit Neumann Hoffman code. The 10 times longer C/A code and Bandwidth of L5 signal has significantly improved the SNR and spatial resolution as compared to L1[8]. Improved signal structure will also improve service availability and position accuracy.

The received GPS signals have very low SNR due to the long distance (20,200km) covered. Since the signals are transmitted using DSSS (Direct sequence spread spectrum) techniques, an effective processing gain can be obtained by correlating the received signal with the locally generated sequence thus improving the SNR. It is the cross correlation property of PRN sequences that provide processing gain and allow to acquire and detect the GPS signals which are below 16dB background thermal noise level and make the detection of week signals possible, where the processing gain is given by

$$Processinggain = 10log\frac{chiprate}{datarate} \tag{2}$$

Further processing gain obtained by correlating the reflected signals for longer period of time allows the reception of weak signals from an altitude of aircraft having antenna with a diameter of few centimeters[9]. The SNR of the reflected GPS signal received can be improved by adding processing gain obtained by correlating the direct and reflected signals received.

$$SNR = \frac{PtGtGr\lambda^2\sigma}{(4\pi)^3 R1^2 R2^2 KTB_n} G_{sp} N^{0.8} \tag{3}$$

Where the processing gain is Gsp and N the maximal non coherent samples.In non coherent summation the desired gain can be achieved by using larger values of N, which results in improved SNR due to longer summation time.

2. Imaging System

This section describes the formation of an image in an area of interest using the reflected GPS L1 and L5 frequency signals based on SAR techniques, followed by comparison of simulated results. The simulation for image reconstruction of target in an area of interest was carried out in MATLAB in two steps. In first step the data received from the (ADC) analogue to digital converter of the RF front end is synthesized and in second step image reconstruction is carried out utilizing this digitized data. The information available to the image reconstruction engine was digitized GPS data, satellite ephemerides and receiver location. Delay offset calculated for the direct and reflected signals are calculated based on the satellites and receiver trajectories and are further used for range calculations. Simulation is carried out for the stationary targets in search area of $2000m^2$, and receiver is moving with velocity of 300 m/sec. An assumption is made that target will always occupy an area of 20m2.The target area is divided into bins and received signal is correlated with the direct signal using a matched filter technique. The output of the matched filter is given by:

$$y(\tau) = \sum_{-\frac{T_s}{2}}^{\frac{T_s}{3}} S_r S_r^*(T_s - \tau), \tag{4}$$

where Sr is the received signal and Ts is the integration time, τ is delay .The signal received is considered to be linear FM chirp signal as the GPS satellite is moving with constant velocity. LFM signal has good pulse compression properties when matched filter is used to improve resolution at receiver. The correlation process is carried out for each sample received and the value is stored in a 2D matrix. The matrix is scanned for each instant of time and maximum correlation value indicated the target location. The parameters used for the simulation are summarized in Table 1.

Table 1: Parameters for Simulation.

S.No.	Target to Receiver,Range,R2 (m)	L1(SNR),dB
1	Target1,coordinates	[200,,0,6378000]
2	Target2,coordinates	[-200, 0,,6378000]
3	Receiver_,coordinates	[5000, -5000, 6378000]
4	Receiver_,velocity	[300, 0, 0]
5	SV_,involved	1,7,9,14,16,22,25,26,27
6	Reference_,SV	4
7	Noise	16dB
8	Attenuation	0.5
9	Integration,Time	0.1

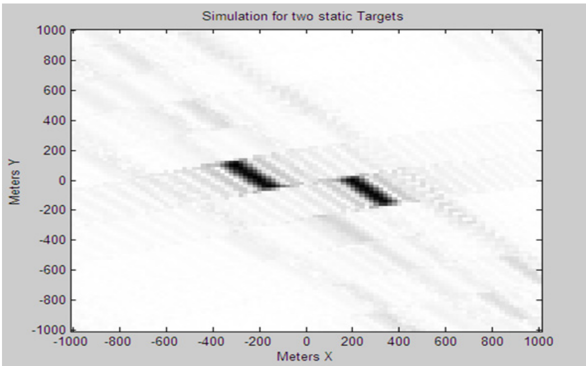

Fig. 2: Target Detection with L1 signal and Integration Time of 0.1 sec, 0dB noise

3. Results and Analysis

It is informed that the simulation is carried out at different integral time for both reflected GPS L1 and L5 signals. Initially simulation is carried out for GPS L1 signal at observation time of Ts=0.1 seconds and without noise. The image reconstructed for the ground based target based on reflected GPS L1 signal is shown in Fig 2. The results show that the target can be differentiated with an acceptable resolution and SNR for the received signal was almost 21dB.A higher value of SNR indicated the stronger signal strength as compared to noise level. As the target to receiver range increases the SNR at the desired point decreases due to free space losses resulting in reduction in signal level.

In a practical scenario there is always noise introduced in wireless communication, so a noise of 16dB was introduced and simulation was carried out for same observation time i.e. Ts=0.1 sec, while keeping all other parameters the same. The simulated results are shown in Fig 3. This resulted in an image with the background noise and system resolution has been degraded, the SNR achieved is 21.303dB.

The image resolution can be improved by simulating the scenario for larger integration time of 0.2 sec and same noise value. The simulation result is shown in Fig 4 which reveals that the image resolution has been improved but more time is required to generate the image.

So far an ideal scenario is simulated for L5 signal without noise while a practical system always have some noise and to show its effect on the image quality a noise of 16dB was introduced and simulation for GPS L5 reflected signal was carried out for the same observation time of 0.1 seconds. The results are shown in Fig 6. The results depict that the image quality is reduced due to additive noise but the targets are still visible. The results show that for the similar

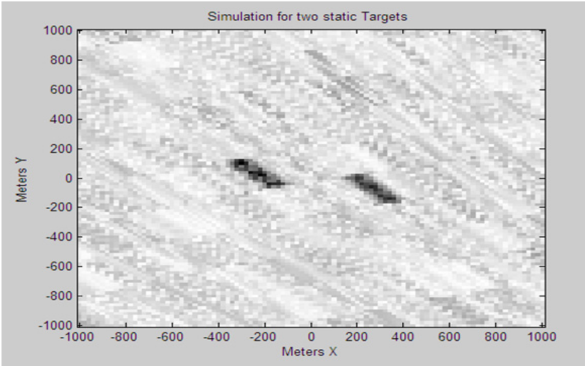

Fig. 3: Target Detection with L1 signal and Integration Time of 0.1 sec, 16dB noise

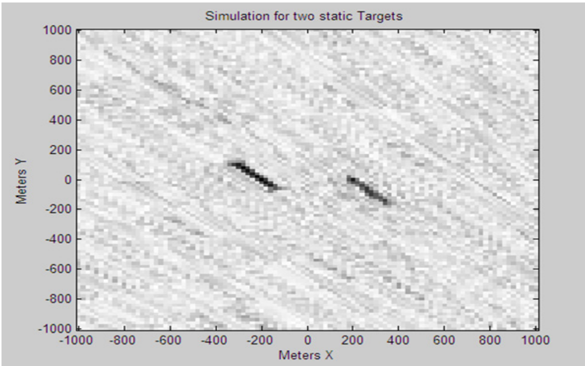

Fig. 4: Target Detection with L1 signal and Integration Time of 0.2 sec, 16dB noise

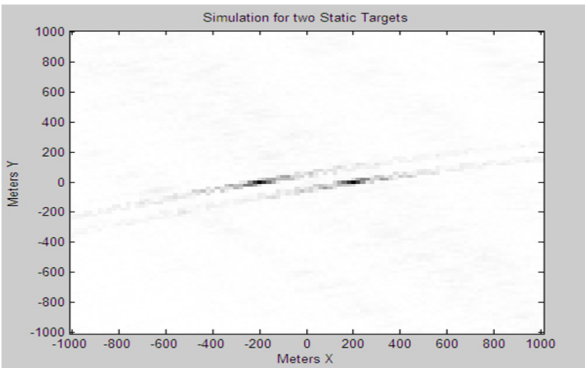

Fig. 5: Target Detection with L5 signal and Integration Time of 0.1 sec, 0dB noise

scenario and same integration time the SNR achieved for the GPS L5 signal is higher than L1, as L5 has 10 times more bandwidth and 10 times longer C/A codes as compared to L1. The higher value of SNR increases the spatial resolution of the image, thus the resultant image exactly pin points the target location.

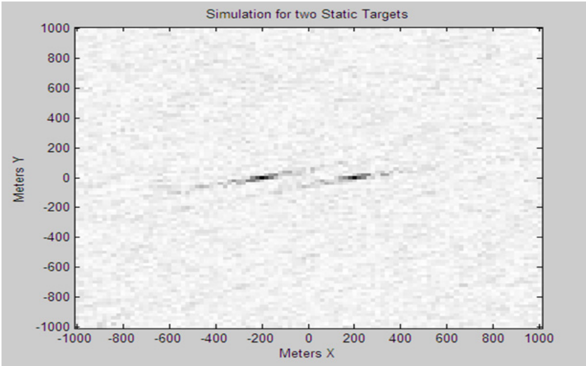

Fig. 6: Target Detection with L5 signal and Integration Time of 0.1 sec, 16dB noise

4. Conclusion

This paper describes the power budget analysis and image formation of targets within area of interest for both GPS L1 and L5 reflected signals based on SAR techniques. From the simulation results it is concluded that the GPS L5 signal has more SNR at receiver end than GPS L1 for same target range and hence image generated has better spatial resolution than L1 signal. Moreover, by increasing the observation time the resolution of the image reconstructed has improved which in turn has improved output SNR. Further work will concentrate on the acquisition of actual GPS L5 data and preparation of passive imaging system using these signals and based on SAR signal processing techniques.

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